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ECBC-TR-727

ACTIVE RANGE OF MOTION WITH INDIVIDUAL PROTECTIVE EQUIPMENT: SELF-CONTAINED BREATHING APPARATUS AND LEVELS B AND A CONFIGURATIONS

David M. Caretti

RESEARCH AND TECHNOLOGY DIRECTORATE

October 2009

ABERDEEN PROVING GROUND, MD 21010-5424

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
XX-10-2009	Final	Dec 2008 - Apr 2009

4. TITLE AND SUBTITLE

Active Range of Motion with Individual Protective Equipment:
Self-Contained Breathing Apparatus and Levels B and A Configurations

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Caretti, David M.

5d. PROJECT NUMBER
9NBNN4

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
DIR, ECBC, ATTN: RDCB-DRP-R, APG, MD 21010-5424

8. PERFORMING ORGANIZATION REPORT NUMBER
ECBC-TR-727

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Institute of Standards and Technology/ Office of Law Enforcement Standards, Gaithersburg, MD 20899-8102

10. SPONSOR/MONITOR'S ACRONYM(S)
NIST/OLES

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The purpose of this investigation was to quantify active range of motion (AROM) of individuals performing head, upper body, and leg movements with and without personal protective equipment with a focus on Levels B and A protection categories. Fifteen volunteers aged 33 ± 6 yr (mean ± SD) completed head, upper body, and lower body exercises to assess AROM under the following conditions of individual protective equipment (IPE) wear: no IPE, self-contained breathing apparatus (SCBA), and Levels B and A protective items. Head AROM was not substantially affected while wearing the SCBA, but AROM performance was reduced for both Levels B and A protection conditions. Upper body movement restrictions due to SCBA and Levels B and A conditions were evident for most AROM activities but were greatest during thoracic flexion and rotation. Comparisons in AROM results among IPE conditions suggest that the SCBA system was the overriding influence in restricting thoracic movements. Even though substantial decrements in performance were found for specific head and upper body AROM variables, few IPE-imposed restrictions on lower body movements were observed.

15. SUBJECT TERMS

Individual protective equipment
Self-contained breathing apparatus (SCBA)
Chemical/biological suit
Level B protection
Level A protection
Active range of motion

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Sandra J. Johnson
U	U	U	UL	27	19b. TELEPHONE NUMBER *(include area code)* (410) 436-2914

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PREFACE

The work described in this report was authorized under Project No. 9NBNN4, National Institute for Occupational Safety and Health/National Institute of Standards and Technology Respirator Standards Development. This work was started in December 2008 and completed in April 2009.

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Acknowledgments

The author would like to thank Cindy Ching (Science Applications International Corporation) for enthusiastic support with the administration of this investigation. In addition, sincere thanks are extended to each and every test participant for volunteering their time and displaying patience in the course of the numerous test iterations. This work would not have been possible without the financial support of the National Institute of Standards and Technology/Office of Law Enforcement Standards.

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ACTIVE RANGE OF MOTION WITH INDIVIDUAL PROTECTIVE EQUIPMENT: SELF-CONTAINED BREATHING APPARATUS AND LEVELS B AND A CONFIGURATIONS

1. INTRODUCTION

Personal protective equipment (PPE) is divided into four categories based on the level of protection afforded: Levels A, B, C, and D.[1,2] In brief, Level D generally constitutes a work uniform affording minimal protection, which is worn for nuisance contamination only. Level C items include full-face or half-mask air-purifying respirators, hooded chemical-resistant clothing, and chemical-resistant gloves generally worn when atmospheric contaminants are known. Level B protection requires positive-pressure respiratory protection, but a lesser level of skin protection. As such, Level B equipment usually includes a self-contained breathing apparatus (SCBA) with a full-facepiece mask, hooded chemical-resistant clothing, and chemical-resistant gloves and boots, at a minimum. Finally, Level A protection, providing the highest level of respiratory, skin, and eye protection, constitutes a fully-encapsulating chemical suit worn over an SCBA. In general, as levels of protection increase from categories D to A, the equipment becomes bulkier and more cumbersome for the user. However, few empirical data quantify movement restrictions due to wear of the differing levels of protective equipment. Because individual protective equipment (IPE) should meet the needs and requirements of end users, body range of motion information that defines movement restrictions according to protection levels needs to be quantified to support functional design to accommodate the needs of end-users.

Previous efforts conducted by the U.S. Army Edgewood Chemical Biological Center (ECBC) quantified the effects of chemical biological (CB) and ballistic IPE on head and body active range of motion (AROM).[3] This earlier work measured AROM associated with a full-facepiece, negative-pressure air-purifying respirator with and without the addition of a chemical protective suit, ballistic protective helmet, and body armor. The highest level of CB protection provided by wear of the negative-pressure air-purifying respirator with the chemical protective suit of this study would be classified as Level C at best. As such, the AROM findings of the study are limited to similar CB protective postures and may not be generalized to include other IPE configurations. Additional testing is needed to determine AROM for other classification levels of protective gear. Therefore, the purpose of this investigation was to quantify AROM of individuals performing common head, upper body, and leg movements with and without PPE with a focus on Levels B and A protection categories.

2. METHODS

2.1 Experimental Procedures

Fifteen volunteers (ten males and five females) between the ages of 25 and 43 yr [33 ± 6 yr; mean ± standard deviation (SD)] participated in this study. The subjects weighed 81.3 ± 14.7 Kg and were 179.5 ± 11.9 cm tall. The volunteers were civilians employed either at ECBC or Science Applications International Corporation. Signed informed consent was obtained for all subjects upon completion of volunteer agreement paperwork. Each volunteer also completed the Occupational Health and Safety Administration (OSHA) Regulation 29 CFR 1910.134 Respirator Medical Evaluation Questionnaire and was cleared for respirator wear and testing.

The specific IPE configurations used in this investigation are listed in Table 1 and pictured in the Appendix. An Interspiro Spiromatic-S (Interspiro, Pleasant Prairie, WI) SCBA was worn for all conditions requiring respirator wear. The Interspiro Spiromatic-S is National Institute for Occupational Safety and Health certified. The SCBA configuration used for testing included the Interspiro full-facepiece respirator, a padded harness with wide shoulder straps and a waistbelt, and an air cylinder. All components of the SCBA system weighed 13.7 Kg. The SCBA was worn according to the manufacturer's directions; however, the device was not operated to deliver respirable air from the back-mounted gas cylinder. The respirator's integrated ambient air hatch was locked in the open position to provide fresh ambient air instead.

The active wear clothing conditions involved the wear of T-shirts, shorts, socks and sneakers, which each subject was instructed to bring to the test facility. A Tychem® SL - High Performance Level B Chemical Suit (DuPont Personal Protection, Richmond, VA), with an integral hood, elastic wrist closures, and integral boot covers, was worn for the Level B test condition. Tychem® SL is a lightweight fabric designed to provide protection against a broad range of industrial chemicals. A Responder™ Level A (Life-Guard, Inc., Guntersville, AL) chemical suit was worn for the Level A configuration. The Responder™ Level A is a totally encapsulating suit with a large face visor designed to provide the highest level of protection from chemical contaminants. Each subject was sized and fitted for all IPE items by an experienced test administrator before testing began.

Table 1. AROM Experimental Test Conditions

Condition	IPE Configuration
Control	Active wear clothing without IPE
SCBA	SCBA with active wear clothing
Level B	SCBA and Level B chemical suit
Level A	SCBA and Level A chemical suit

Upon arrival at the lab, the subjects changed into active wear clothing and were prepped for testing. The subjects then donned nine body-mounted range-of-motion sensors for measuring the position and orientation of specific body parts during AROM testing. Active range of motion was measured using the MotionStar™ Wireless system (Ascension Technology Corporation, Burlington, VT). The MotionStar™ is a six degree-of-freedom measurement system that uses pulsed direct current magnetic fields to simultaneously track the position and orientation of sensors located on individuals within 3.05 m of a transmitter. The system consists of body mounted sensors, body mounted electronics, and a base station. There were no wires from the user's body to the base station, so the user was completely free to move about without a trailing cable.

Each sensor measured the position and orientation of the specific body part to which it was attached. A sensor consisted of a 2.5 cm cube attached via a wire to an electronics unit that was mounted in a cloth pouch attached to a small (18 x 14 x 5 cm) backpack that weighed 1.5 Kg with the electronics unit. Sensors were attached to sensor mounts on stretchable bands that went around the head, legs, and arms of a subject. The sensors were attached to the following nine locations of the body: left and right arms, left and right wrists, left and right legs, back of the head (external occipital protuberance), chest (jugular notch of the sternum), and lower abdomen (below the umbilicus in the transtubercular plane).

The chest and lower abdomen sensors were placed directly on the skin and secured with pieces of elastic adhesive bandage (Elastoplast®, BSN Medical, Vibraye, France). Care was taken to ensure that sensor placements did not contact or interfere with the SCBA shoulder harnesses or waistbelt. Sensor positions on the body and within the measuring field were defined by digitization of multiple body joints and landmarks while the subject stood in a neutral position (i.e., arms hanging at the side and head looking forward) in the center of the measurement field.

Testing commenced once operation of the AROM equipment was validated. Experimental test conditions were administered in order starting with Control conditions, followed by Mask, Suit, Helmet, Helmet + weight, Armor, and Armor + collar conditions. Test personnel assisted subjects with IPE donning. Active range of motion for various body joints was measured and recorded as test participants performed the movements listed in Table 2.

Test personnel demonstrated how to perform each AROM activity prior to commencement. The subjects were allowed to practice body movements until they felt comfortable performing each exercise and test personnel determined that the motions were done proficiently. Each subject performed a minimum of two repetitions of each movement for each test condition. The duration for a single activity was 20 s and each motion was performed repetitively until the subject was instructed to stop. The movement sequence was arbitrarily selected to ensure consistency when taking AROM measurements.

Test subjects were instructed to perform activities until their movements were stopped by muscle tightness, slight discomfort, or until a substitution movement occurred. Companion software (The MotionMonitor™, Innovative Sports Training, Inc., Chicago, IL) recorded joint angles during each data collection period. Range of motion results were presented graphically on-screen immediately upon completion of data collection and were visually reviewed by test administrators to screen for obvious data acquisition errors (e.g., loss of signal or distorted movements). The subjects rested for 10 min between test conditions.

2.2 Analysis of AROM Data

The list of AROM variables analyzed for each AROM exercise is presented in Table 3. For descriptive statistics, ANOVA were performed to compare AROM results among test conditions based on the individual body activities. Active range of motion performance ratings (AROM PR) were also calculated according to the following equation

$$\text{AROM PR}_{IPE}\ (\%) = \left(\frac{AROM_{IPE}}{\sum_{i=1}^{n} AROM_{Ci} \Big/ n} \right) \times 100$$

where $AROM_{IPE}$ = joint range of motion for a given AROM activity and IPE test condition and $AROM_C$ = joint range of motion under Control conditions for the same activity. Performance rating calculations provided estimates of the percentage of performance of each test participant with IPE compared to the non-IPE condition. As such, AROM PR results are relative and scaled between 100 (no performance degradation) and zero (complete performance degradation). Bonferroni's post-hoc analysis was computed to determine significant differences among group means if a significant F statistic was initially obtained. Statistical significance was accepted at the $p < 0.05$ level.

Table 2. Activities/Exercises Used to Assess AROM

Range of Motion Activity	Activity Identifier	Description
Rotate head side-to-side	Head S2S	Standing in place, a subject slowly turned his/her head from side-to-side
Flex head up and down	Head Nod	Standing in place, a subject slowly moved his/her head up and down
Flex head to the left and right	Head Lat Flex	Standing in place, a subject slowly flexed his/her head to the left as if to touch the left ear to the left shoulder and then repeated the motion to the right
Upper arm movements	Arms Up	From a standing position, a subject raised both arms sideward and upward with the palms facing forward until the hands touched above the head or moved as far as possible over the head without bending the elbows
Twisting at waist	Twist	While standing, a subject extended his/her arms perpendicular to the sides of torso and twisted at the waist from side-to-side
Squat	Squat	Standing with feet shoulder width apart, subjects slowly bent at the knees while keeping the upper body erect; once the subject reached the full range of motion with knees bent, he/she slowly returned to the standing position while keeping the upper body erect
Reach for floor and ceiling	Bend & Reach	Standing in place with arms at side, subjects bent at the waist and reached for the floor with both arms extended, returned to standing, fully extended arms above the head, and returned to standing with arms at the side
Forward lunge	Lunge	From a standing position, subjects stepped forward as far as possible with one leg, bending the knee about 90°, and holding for 3 s; subjects then returned to the standing position and repeated the motions with the opposite leg
Leg lifts	Leg Lift	While standing, subjects lifted one foot off the ground as high as possible with the leg bent at the hip and knee and then repeated the same motion for the other leg

Table 3. AROM Variables Analyzed According to Body Motions

Range of Motion Activity	AROM Variables
Head S2S	Left and right cervical rotation; total cervical rotation
Head Nod	Cervical flexion and extension; full range of flexion and extension
Head Lat Flex	Left and right cervical lateral flexion; total lateral flexion
Arms Up	Shoulder abduction
Twist	Left and right thoracic rotation; total thoracic rotation
Squat	Left and right hip and knee flexion
Bend & Reach	Shoulder flexion and thoracic flexion
Lunge	Left and right hip and knee flexion
Leg Lift	Left and right hip and knee flexion

3. RESULTS

3.1 AROM of the Cervical Spine during Head Motions

Results for cervical AROM data for all head movements are presented in Figures 1 through 3. The data are expressed as mean ± SD. Active range of motion data represent maximal angles of joint movement from the neutral (zero) position as recorded during digitization of the nine AROM sensors. Unintended displacement of AROM sensors and subject availability for testing resulted in differences in the number of data points analyzed for each IPE test condition.

All IPE test conditions significantly reduced cervical rotation to the left during the Head S2S activity compared to Control (Figure 1). Leftward cervical rotation was also significantly less for both the Levels B and A conditions compared to the SCBA configuration. No differences between Levels B and A were found. Cervical rotation to the right was also significantly less for both conditions compared to Control, but neither condition differed from the SCBA results.

For the Head Nod activity, cervical extension was reduced significantly for the Level A condition compared to Control, SCBA, and Level B conditions (Figure 2). However, no significant differences among Control, SCBA, and Level B conditions were observed for cervical extension. In contrast, cervical flexion was significantly less for the Levels B and A IPE configurations compared to both Control and SCBA conditions (Figure 2). Although cervical flexion was reduced for the SCBA condition compared to control, the difference between conditions was not statistically significant. Likewise, no differences were found between the Levels B and A conditions.

Left lateral flexion of the head was not significantly different among the IPE test conditions (Figure 3). Lateral cervical flexion to the right was reduced significantly during the Levels B and A trials compared to the Control condition; however, no difference between Control and SCBA was found. Reductions in right lateral flexion did not differ between the Levels B and A conditions.

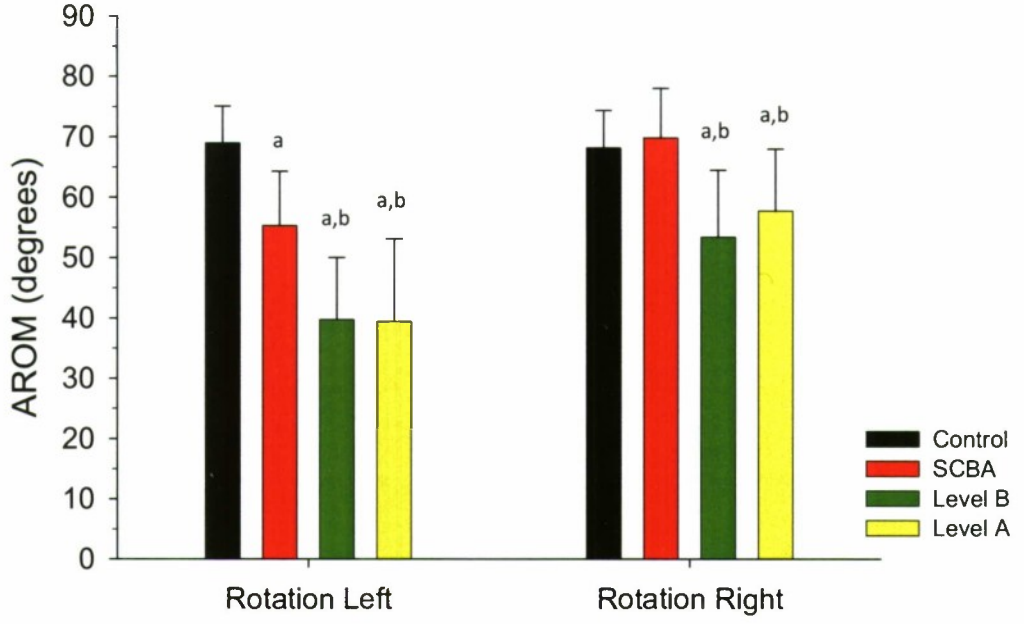

Figure 1. AROM for Cervical Rotation during Head S2S Activity for Each IPE Condition. Error bars represent 1 SD. Letters identify significant ($p < 0.05$) differences among conditions according to the following: a = different vs. Control, b = different vs. SCBA, and c = different vs. Level B.

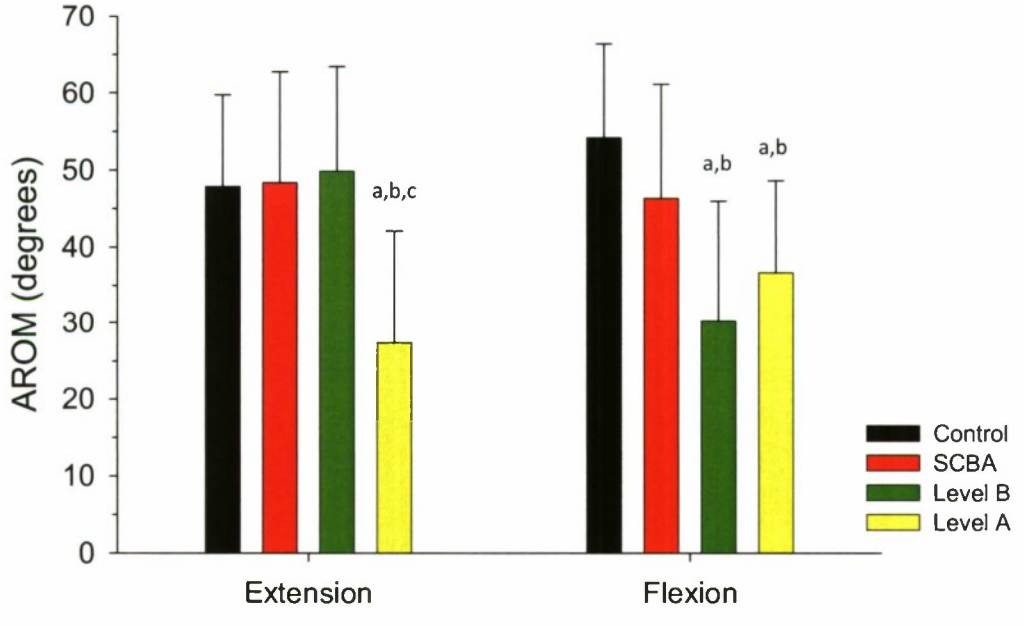

Figure 2. AROM for Cervical Flexion and Extension during Head Nod Activity. See Figure 1 for definitions of the letters used for identifying differences among conditions.

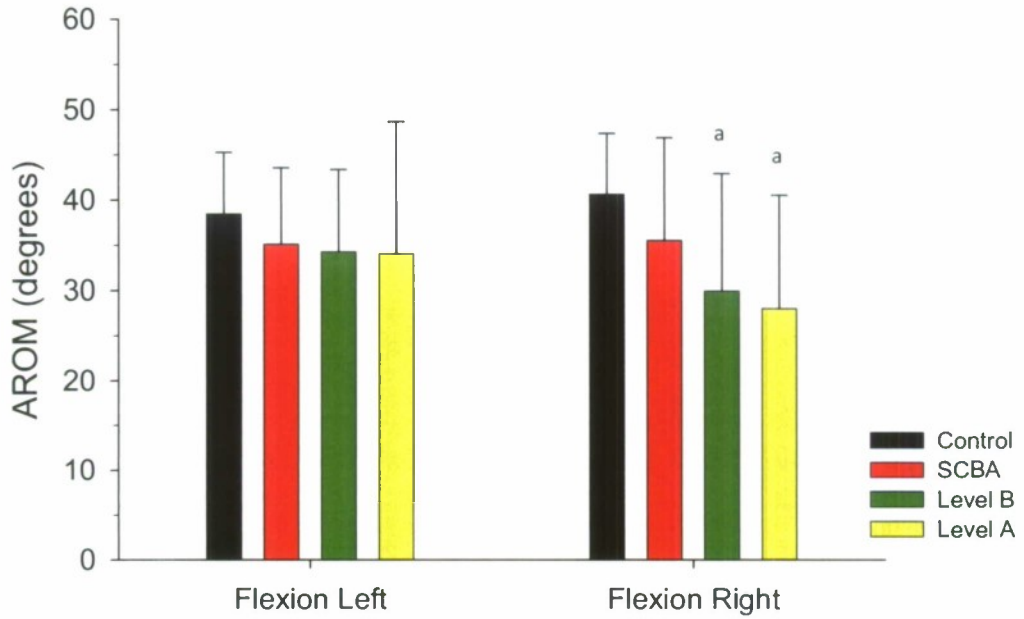

Figure 3. AROM for Lateral Cervical Flexion to Left and Right for Head Lat Flex Activity. See Figure 1 for definitions of the letters used for identifying differences among conditions.

Full range of movement AROM data for head activities are presented in Table 4. Compared to Control, wearing the SCBA without a protective suit had no significant impact on full AROM for cervical flexion and extension or right and left lateral cervical flexion. However, the SCBA significantly reduced total cervical rotation compared to the Control condition. Levels B and A conditions significantly decreased cervical flexion and extension and total cervical rotation compared to both Control and SCBA conditions, but total lateral head flexion was not different among SCBA and Levels B and A conditions. The only significant difference found between Levels B and A trials was for total cervical flexion and extension. The greatest total AROM decrement was seen in cervical flexion and extension for the Level A condition.

Performance rating results for head total AROM showed decrements in performance of less than 10% on average for the SCBA test condition regardless of AROM activity (Table 5). Active range of motion PR for Levels B and A conditions were identical for total right-to-left lateral cervical flexion and did not differ significantly from SCBA PR results. The Level B condition caused about a 21% decrement in total cervical flexion and extension and about a 32% reduction in total cervical rotation. Level B AROM PR results differed significantly compared to SCBA data for each of these AROM activities. The Level A condition reduced total cervical flexion and extension by roughly 37% and resulted in about a 29% decrement in total cervical rotation. Level A AROM PR results also differed significantly compared to SCBA data for each of these AROM activities. Likewise, a significant difference between Levels A and B AROM PR data existed for total cervical flexion and extension.

Table 4. Average Total AROM (±SD) of Head Movements for Each IPE Condition

Condition	N	Flexion & extension (°)	Lateral Flexion (°)	Rotation (°)
Control	30	102.1 ± 14.6	79.1 ± 12.3	137.2 ± 11.1
SCBA	30	94.7 ± 13.9	70.6 ± 13.3	125.2 ± 11.5[a]
Level B	30	80.0 ± 17.8[a,b]	64.2 ± 14.8[a]	93.2 ± 17.6[a,b]
Level A	30	64.0 ± 14.5[a,b,c]	62.0 ± 10.9[a]	+95.9 ± 20.5[a,b]

[a] = *significantly different from Control*
[b] = *significantly different from SCBA*
[c] = *significantly different from Level B*

Table 5. Average Total AROM PR (±SD) of Select Head Movements for Each IPE Condition

Condition	N	Flexion & extension (%)	Lateral Flexion (%)	Rotation (%)
SCBA	30	93 ± 9	90 ± 13	91 ± 8
Level B	30	79 ± 16[b]	82 ± 17	68 ± 13[b]
Level A	30	63 ± 13[b,c]	82 ± 17	71 ± 16[b]

[b] = *significantly different from SCBA*
[c] = *significantly different from Level B*

3.2 AROM for Upper Body Motions

Results for AROM data for upper body movements of Arms Up (shoulder abduction), Twist (thoracic rotation), and Bend & Reach (thoracic flexion and shoulder flexion) are presented in Figures 4 through 7. Neither left nor right shoulder abduction was impacted with the SCBA compared to the Control condition (Figure 4). Both Levels B and A IPE concepts significantly reduced left shoulder abduction compared to both the Control and SCBA test conditions. Right shoulder abduction was also significantly less for Levels B and A conditions compared to Control but did not differ from SCBA results. No differences were observed between the Levels B and A conditions for either shoulder.

Thoracic rotation, measured during the Twist AROM activity, decreased significantly with the SCBA and Levels B and A IPE configurations compared to Control for both leftward and rightward rotation (Figure 5). Although AROM decreased as the level of IPE protection increased from SCBA to Level A in both directions, no significant differences were found among SCBA and Levels B and A conditions.

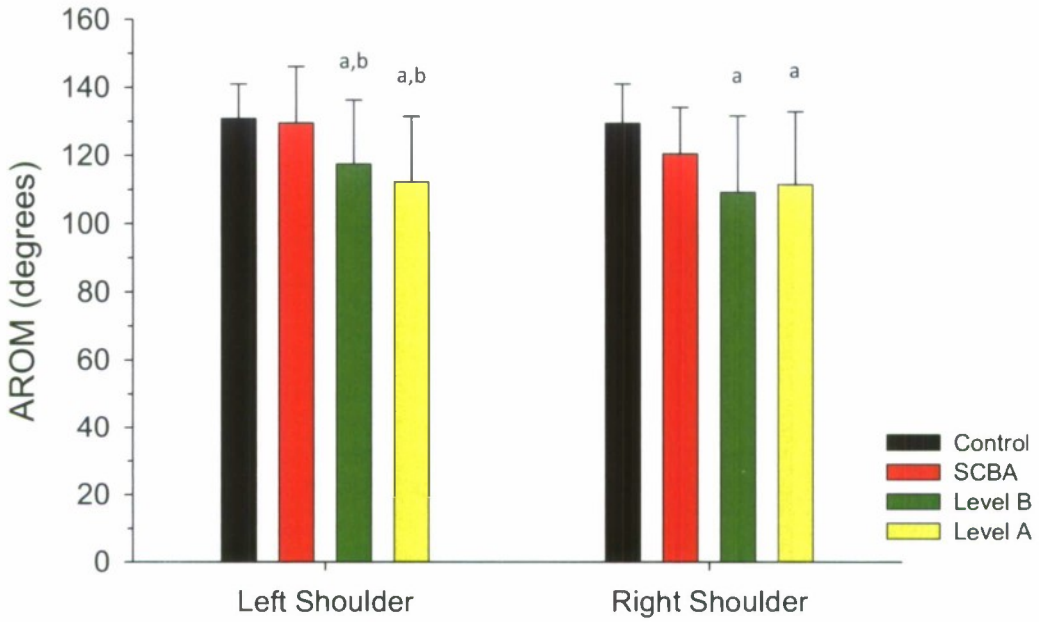

Figure 4. Left and Right Shoulder Abduction for Arms Up AROM Activity. Refer to Figure 1 for definitions of the letters used for identifying differences among conditions.

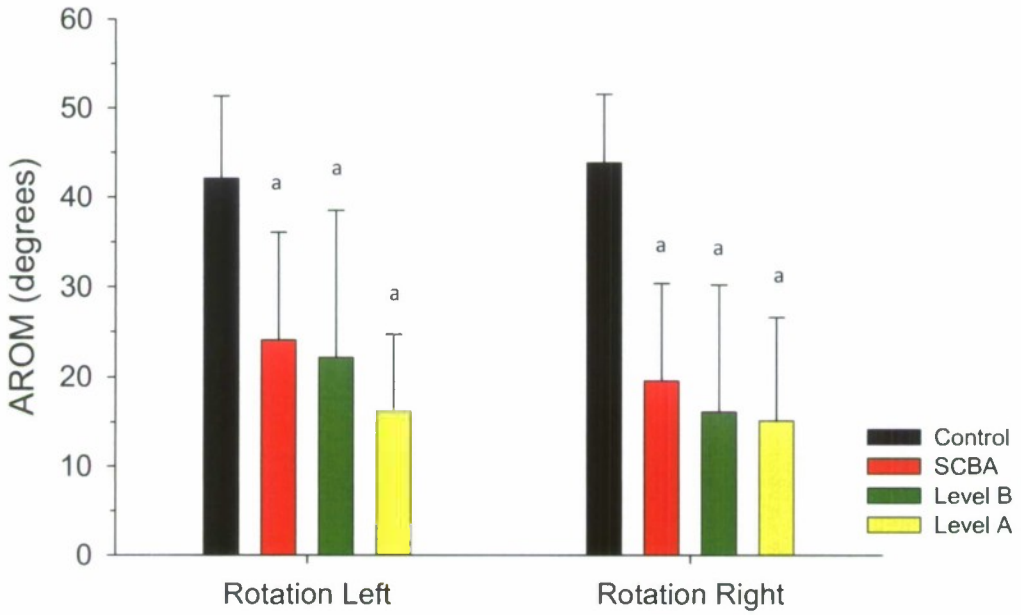

Figure 5. Left and Right Thoracic Rotation for Twist Exercise. See Figure 1 for definitions of the letters used for identifying differences among conditions.

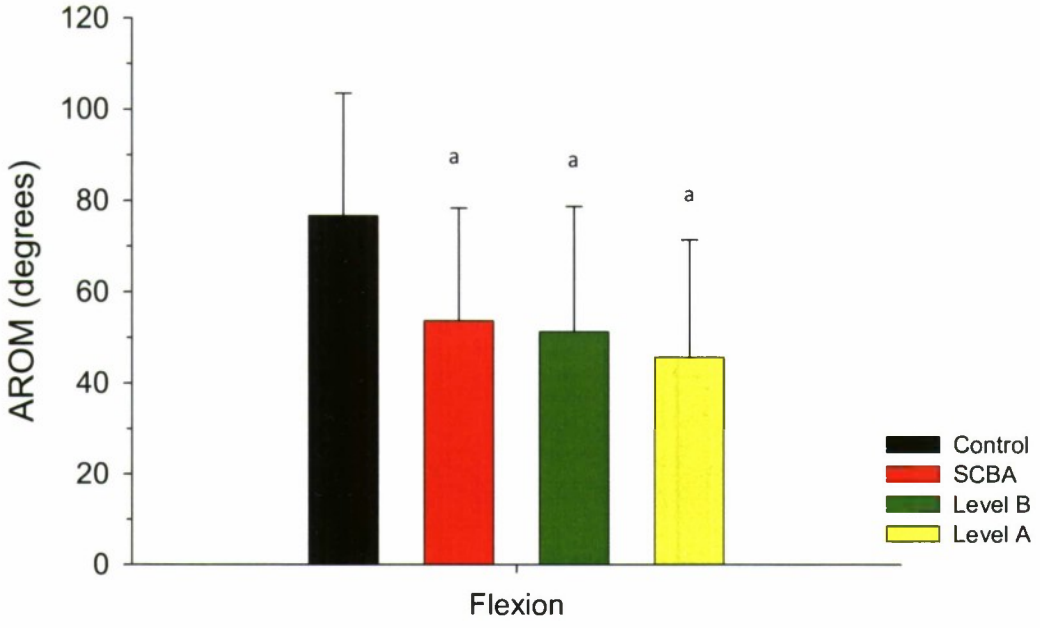

Figure 6. Thoracic Flexion during Bend and Reach AROM Activity. Refer to Figure 1 for definitions of the letters used for identifying differences among conditions.

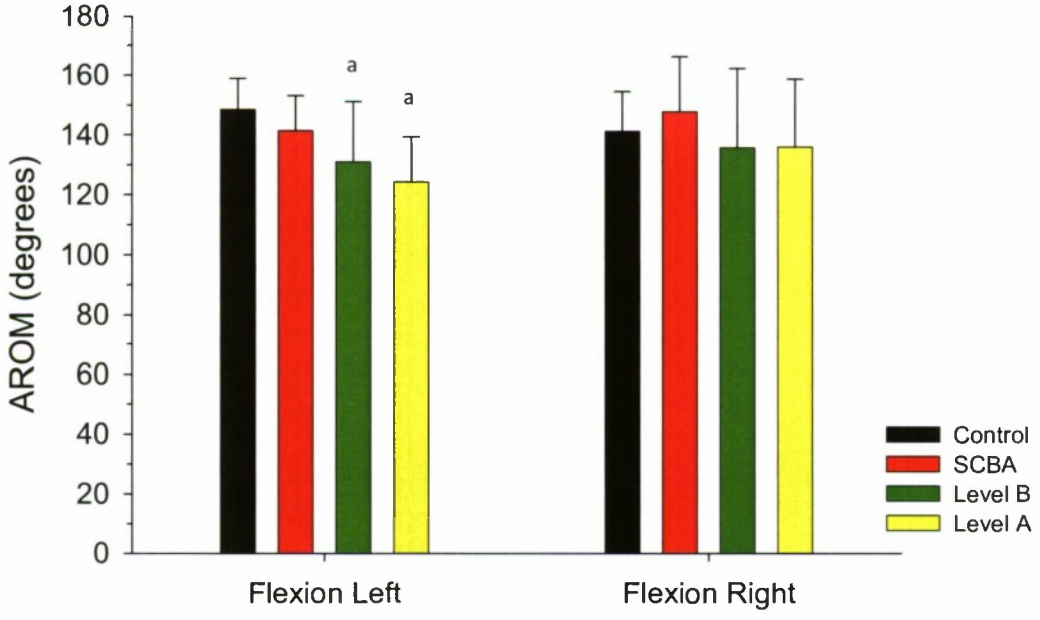

Figure 7. Left and Right Shoulder Flexion for Bend and Reach Exercise. See Figure 1 for definitions of the letters used for identifying differences among conditions.

Active range of motion variables assessed during the Bend & Reach activity included thoracic flexion and shoulder flexion. Thoracic flexion was significantly reduced for SCBA and Levels B and A conditions compared to Control (Figure 6). No differences in thoracic flexion were observed among the SCBA and Levels B and A conditions. Right shoulder flexion did not differ among experimental conditions for the Bend & Reach exercise (Figure 7). In contrast, left shoulder flexion was significantly limited for Levels B and A conditions compared to Control. No differences in left shoulder flexion were observed among the SCBA and Levels B and A conditions.

Average AROM PR results for upper body motions are presented in Table 6. Decrements in total thoracic rotation performance were substantial (>50%) for all conditions. The Level A condition resulted in the lowest AROM PR values for total thoracic rotation, which differed significantly from the SCBA condition. Thoracic flexion AROM PR results indicated performance decrements from 30 to 40% for IPE conditions, with the greatest decrement associated with the Level A condition. No significant differences in AROM PR values were observed in thoracic flexion among conditions.

Performance ratings were identical among conditions for right shoulder abduction and ranged between 85 and 94% on average. The range of AROM PR for left shoulder abduction was between 86 and 99% with the greatest decrement associated with the Level A condition. Average AROM PR results for left shoulder abduction differed significantly for Levels B and A conditions compared to the SCBA. Left shoulder flexion AROM PR values were between 85 and 96% on average for all IPE conditions and Level A PR results differed significantly from SCBA data. Performance ratings for right shoulder flexion ranged from 94 to 104%, suggesting limited impacts of IPE wear on this AROM variable.

Table 6. Average AROM PR [±SD; (N)] for Upper Body Motions

Condition	Total Thoracic Rotation (%)	Thoracic Flexion (%)	Shoulder Abduction (%)		Shoulder Flexion (%)	
			Left	Right	Left	Right
SCBA	49 ± 16 (29)	71 ± 21 (20)	99 ± 13 (30)	94 ± 12 (30)	96 ± 8 (30)	104 ± 10 (30)
Level B	42 ± 20 (30)	66 ± 24 (24)	90 ± 16[b] (30)	85 ± 17 (30)	89 ± 13 (28)	94 ± 13[b] (27)
Level A	36 ± 10[b] (30)	60 ± 27 (22)	86 ± 14[b] (30)	87 ± 16 (30)	85 ± 12[b] (28)	96 ± 12[b] (28)

[b] = *significantly different from SCBA*

3.3 AROM for Lower Body Motions

Body movements associated with the activities Squat, Lunge, and Leg Lift included left and right hip flexion and left and right knee flexion. Hip flexion results for all of the lower body motions are shown in Figure 8. With the exception of the difference between Level A and control conditions for left hip flexion while performing the Leg Lift activity, no significant reductions in hip flexion were found among test conditions.

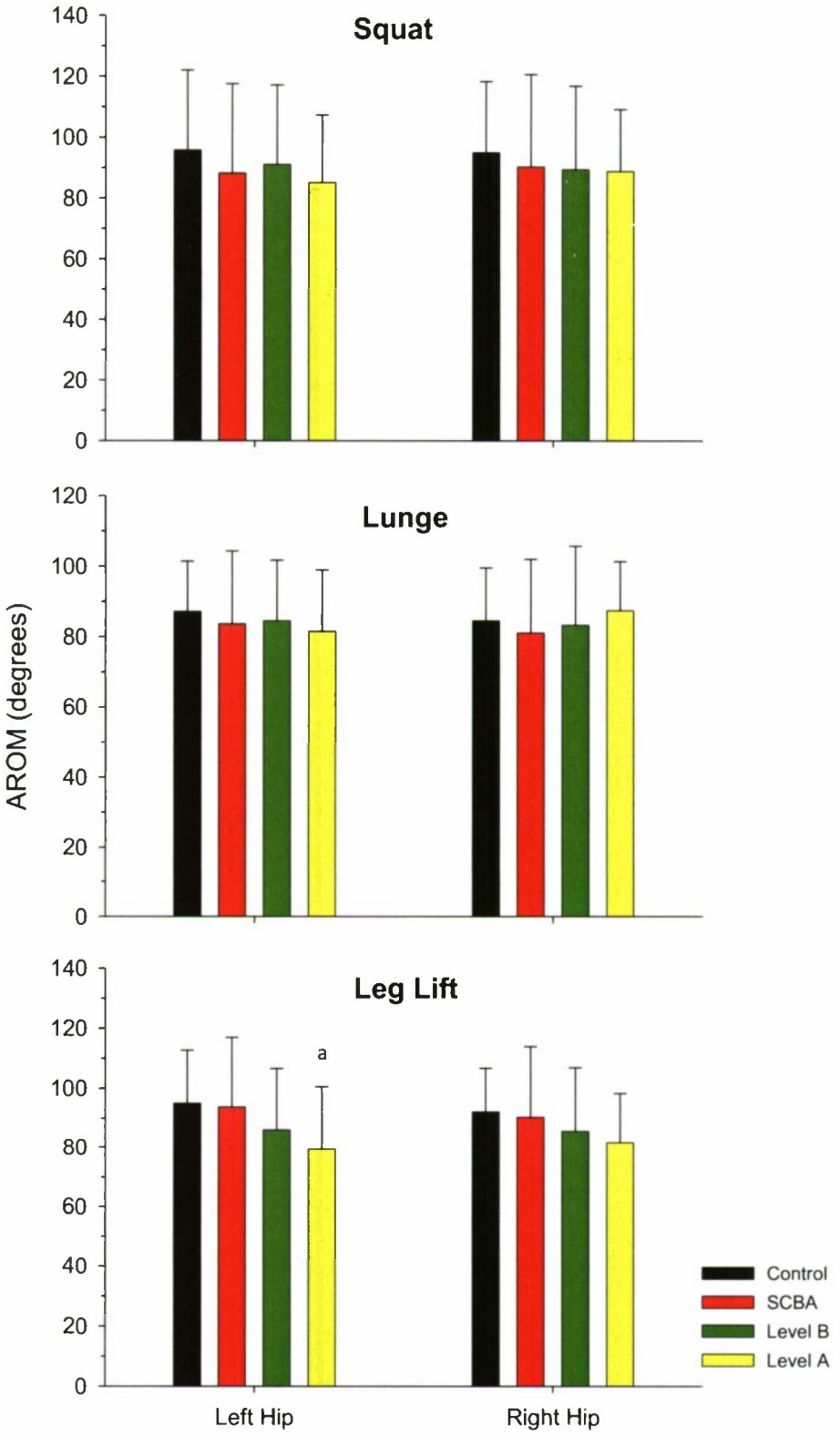

Figure 8. Left and Right Hip Flexion for Each Lower Body AROM Exercise (i.e., Squat, Lunge, and Leg Lift).

Left and right knee flexion results for each of the lower body AROM exercises are presented in Figure 9. As for hip flexion, no significant reductions in knee flexion were found among test conditions with one exception: left knee flexion during the Leg Lift activity was significantly less for the Level A condition compared to all other conditions. Although right knee flexion during Left Lift movements was lower for the Level A concept than the Control, SCBA, and Level B conditions, no significant differences among these conditions were found.

Average AROM PR results exceeded 90% for hip flexion and were comparable for all conditions during both the Squat and Lunge AROM exercises (Table 7). Performance ratings for left hip flexion during Left Lift activities ranged from 83 to 98% and differed significantly between SCBA and Level A conditions. No differences were seen among conditions for right hip flexion for the same AROM exercise. Performance rating data showed little decrement in knee flexion performance among IPE test conditions for the Lunge AROM activity (Table 8). Average PR results for knee flexion were lowest for the Level A condition during the Squat activity, but no differences among the conditions were found. Performance ratings for left knee flexion ranged from 89 to 98% for the Leg Lift activity. Self-contained breathing apparatus and Level A AROM PR values differed significantly for left leg flexion for this activity.

Table 7. Average Hip Flexion AROM PR [±SD; (N)] for Lower Body Motions

Condition	Squat Hip Flexion (%)		Lunge Hip Flexion (%)		Leg Lift Hip Flexion (%)	
	Left	Right	Left	Right	Left	Right
SCBA	95 ± 20 (28)	94 ± 22 (30)	97 ± 18 (27)	96 ± 22 (30)	98 ± 15 (28)	97 ± 18 (30)
Level B	93 ± 20 (28)	92 ± 23 (28)	97 ± 15 (29)	98 ± 21 (30)	90 ± 14 (29)	92 ± 16 (29)
Level A	90 ± 15 (28)	94 ± 15 (28)	94 ± 16 (30)	104 ± 14 (30)	83 ± 15[b] (30)	89 ± 15 (30)

[b] = *significantly different from SCBA*

Table 8. Average Knee Flexion AROM PR [±SD; (N)] for Lower Body Motions

Condition	Squat Knee Flexion (%)		Lunge Knee Flexion (%)		Leg Lift Knee Flexion (%)	
	Left	Right	Left	Right	Left	Right
SCBA	93 ± 11 (28)	96 ± 13 (30)	96 ± 10 (27)	99 ± 10 (30)	98 ± 10 (28)	101 ± 10 (30)
Level B	97 ± 15 (30)	95 ± 14 (30)	101 ± 9 (29)	99 ± 7 (30)	99 ± 7 (29)	101 ± 9 (29)
Level A	86 ± 12 (28)	87 ± 16 (28)	98 ± 12 (30)	98 ± 12 (30)	89 ± 13[b,c] (30)	92 ± 11 (30)

[b] = *significantly different from SCBA*
[c] = *significantly different from Level B*

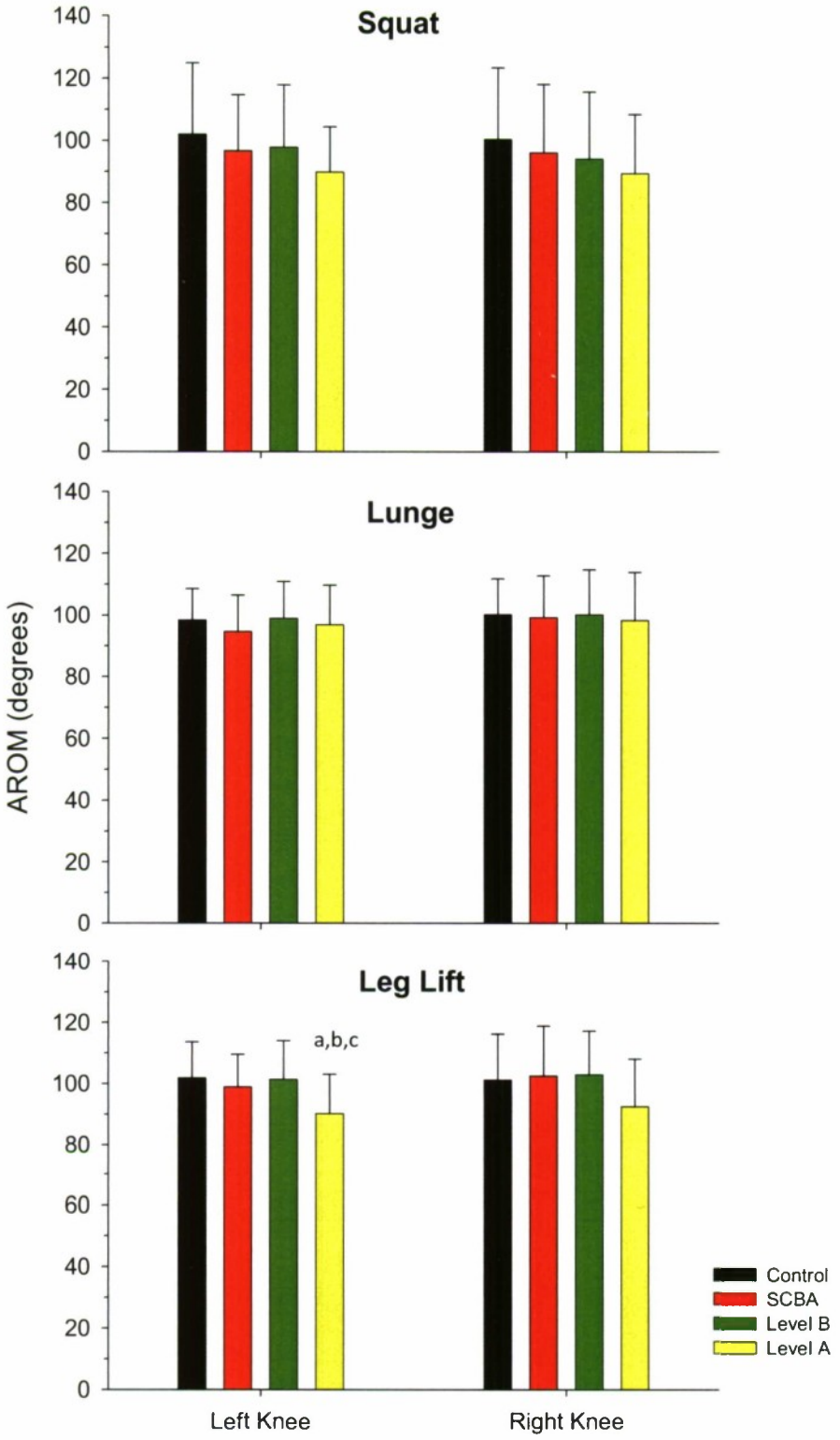

Figure 9. Left and Right Knee Flexion for All Lower Body AROM Activities.

4. DISCUSSION

Reductions in head AROM attributable to the SCBA in and of itself were minimal and were evident primarily during head rotation. Performance decrements with the SCBA averaged 7, 10, and 9% for flexion and extension, lateral flexion, and rotation, respectively. The SCBA related decrements in head flexion and extension and lateral flexion were similar to those reported during the wear of full-facepiece air-purifying respirators.[3,4] In contrast, the 9% head rotation decrement caused by the SCBA was greater than previously found for an air-purifying respirator.[5] These findings suggest that wearing an SCBA limits head AROM more than an air-purifying respirator, but still does not significantly impact head AROM.

Head AROM performance was substantially reduced for both Levels B and A protection conditions. Impacts on leftward and rightward head rotation, as well as head flexion, were significant compared to both Control and SCBA conditions. Despite the vastly different IPE wear configurations of the Levels B (SCBA worn over the chemical-protective suit) and A (SCBA worn underneath the chemical-protective suit) conditions, reductions in head AROM were generally comparable between Levels B and A conditions. The lone exception to this was for head extension, which was significantly reduced by Level A conditions compared to Level B. The limits of head extension with the Level A configuration appeared to result from impacts between the SCBA respirator facepiece and the suit's visor and not from the bulk of the hood material at the back of the head and neck. The substantial performance decrements in total head rotation (Level B = 32%; Level A = 29%) and head flexion and extension (Level B = 21%; Level A = 37%) suggest that user performance of work tasks requiring freedom of head movement could be compromised when either level of protection equipment is worn.

Upper body AROM limitations due to SCBA, Level B, and Level A conditions were evident for most activities; however, thoracic rotation and thoracic flexion were impacted to the largest extent. The significant decrements in thoracic flexion found for the SCBA condition were similar to those associated with the Levels B and A concepts, suggesting that thoracic flexion restrictions were due to the SCBA system and not the chemical-resistant suits worn for Levels B and A protection. Similar reductions in AROM were also seen for the SCBA and Levels B and A conditions in thoracic rotation during the Twist AROM exercise. Because of the significant difference between SCBA and Level A conditions for total thoracic rotation AROM PR, the Level A suit appeared to cause some additional restriction to movement. Even so, these results suggest that the SCBA system was the overriding influence in restricting thoracic movements. With performance decrements ranging from 29 to 40% for thoracic flexion and from 51 to 74% for total thoracic rotation among all conditions, hindrances in performance are likely for tasks requiring these movements.

In contrast to head and upper body AROM, few IPE-imposed restrictions on lower body movements were observed. With the exception of left hip and knee flexion during the Leg Lift activity, no significant differences among conditions were found. Performance rating results also indicated that movement decrements rarely exceeded 10%, an amount that may not be significant in actual wearing and use conditions. These findings suggest that SCBA and Levels B and A wear conditions have minimal impact on lower body AROM. Similar results were previously reported for air-purifying respirator and Level C wear conditions.[3]

5. CONCLUSIONS

This study quantified the effects of self-contained breathing apparatus (SCBA) and Levels B and A individual protective equipment (IPE) items on head and body active range of motion (AROM). Head AROM was not substantially affected while wearing the SCBA, but AROM performance was reduced for both Levels B and A protection conditions. Upper body movement restrictions due to SCBA and Levels B and A conditions were evident for most AROM activities, but were greatest during thoracic flexion and rotation. Comparisons in AROM results among IPE conditions suggest that the SCBA system was the overriding influence in restricting thoracic movements. Even though substantial decrements in performance were found for specific head and upper body AROM variables, few IPE-imposed restrictions on lower body movements were observed. It is not known how AROM restrictions found for SCBA and Levels B and A IPE wear conditions may impact job performance; additional research should be conducted to quantify relationships between AROM decrements and task performance.

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APPENDIX

PHOTOGRAPHS OF SELECT IPE TEST CONDITIONS

SCBA

Level B

Level A